

APPLICATION
FOR
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Entitled
CIRCUIT HAVING POWER MANAGEMENT

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CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Patent Application No. 60/455,826 filed on March 19, 2003, which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not Applicable.

FIELD OF THE INVENTION

[0003] The present invention relates generally to electrical circuits and, more particularly, to electrical circuits for controlling power to a load.

BACKGROUND OF THE INVENTION

[0004] As is known in the art, there are a variety of circuits that limit the energy in a circuit. For example, dimming circuits for lighting applications adjust the brightness of a light source. Exemplary power control, dimming, and/or feedback circuits are shown and described in U.S. Patent Nos. 5,686,799, 5,691,606, 5,798,617, and 5,955,841, all of which are incorporated herein by reference.

[0005] However, known power control/dimmer circuits typically have significant performance degradation for non-linear loads. Some known circuits have feedback from the load that can generate significant Electromagnetic Conductive interference (EMC), which degrades circuit performance and limits use of the feedback.

[0006] FIG. 1 shows an exemplary prior art dimming circuit 10 having a diac D coupled to a triac TR gate. A resistor R and a potentiometer P are coupled as shown. A black wire terminal BLK is coupled to the resistor R and the triac TR and a white wire terminal

WH is coupled to the load LD, which is coupled to the potentiometer P and the triac TR, as shown.

[0007] As shown in FIG. 2, when the voltage across the potentiometer P reaches a predetermined level V_T , the diac D fires and the triac TR enables the circuit to become conductive. An input signal IS has a conductive region CR and non-conductive region NCR based upon when the diac fires.

[0008] While this circuit arrangement may be effective for linear loads, non-linear loads may render the circuit unstable. In addition, storage capacitors and other energy storage devices will charge to a voltage level corresponding to the peak V_p of the input signal. That is, the non-linear load selects the charge voltage level. In addition, current surges are not generated at optimal times and can degrade circuit performance.

[0009] It would, therefore, be desirable to overcome the aforesaid and other disadvantages.

SUMMARY OF THE INVENTION

[0010] The present invention provides a power management circuit that eliminates peak-charging of charge storage elements. With this arrangement, a non-linear load can be energized in a stable and efficient manner. While the invention is primarily shown and described in conjunction with circuits for energizing lamps, it is understood that the invention is applicable to circuits for energizing loads in general in which it is desirable to provide lower power levels, e.g., dimming, as well as overvoltage and current surge protection.

[0011] In one aspect of the invention, a power management circuit includes first and second switching elements coupled across first and second rails for energizing a load, and a first power control circuit coupled to the first switching element. The first power control circuit biases the first switching element to a non-conductive state for a portion of

an AC half cycle during which a peak voltage of the AC half cycle occurs when a voltage across the first and second rails is greater than a predetermined threshold. In one particular embodiment, a period of non-conduction for the first switching element is centered about a peak of the AC signal. With this arrangement, energy storage elements charge to a level that corresponds to the predetermined voltage threshold instead of the peak voltage as in conventional circuits since this predetermined voltage represents the peak voltage.

[0012] In another aspect of the invention, the circuit includes a current sensing circuit coupled to the first switching element for providing current surge protection.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

[0014] FIG. 1 is a schematic diagram of a prior art wall dimmer circuit;

[0015] FIG. 2 is a graphical display of a voltage waveform generated by the prior art circuit of FIG. 1;

[0016] FIG. 3 is a schematic representation of a circuit having power management in accordance with the present invention;

[0017] FIG. 4 is an exemplary circuit implementation of the circuit of FIG. 3

[0018] FIG. 4A is an exemplary circuit implementation of the circuit of FIG. 4 further including exemplary values for component characteristics;

[0019] FIG. 5A is a graphical display of an exemplary voltage waveform generated by the circuit of FIG. 4;

[0020] FIG. 5B is a graphical display of an exemplary current waveform generated by the circuit of FIG. 4;

[0021] FIG. 5C is a graphical depiction of a waveform showing overvoltage protection in accordance with the present invention;

[0022] FIG. 6 is an exemplary circuit implementation of the circuit of FIG. 4 further including current limiting features in accordance with the present invention;

[0023] FIG. 7 is an exemplary schematic implementation of a circuit providing power management in accordance with the present invention;

[0024] FIG. 8 is a further exemplary schematic implementation of the circuit of FIG. 7 further having current limiting features in accordance with the present invention;

[0025] FIG. 9 is another exemplary schematic implementation of a circuit providing power management in accordance with the present invention;

[0026] FIG. 10 is another exemplary schematic implementation of a circuit providing power management in accordance with the present invention;

[0027] FIG. 11 is another exemplary schematic implementation of a circuit providing power management in accordance with the present invention; and

[0028] FIG. 12 is another exemplary schematic implementation of a circuit providing power management in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0029] FIG. 3 shows an exemplary circuit 100 having power management in accordance with the present invention. The circuit 100 includes first and second switching elements 102, 104 coupled in a half bridge configuration for energizing a load 106. A first power control circuit 108 is coupled between a first voltage rail 110 and the first switching element 102 and a second power control circuit 112 is coupled between the second switching element 104 and a second voltage rail 114. First and second mutually coupled inductors L1-1, L1,2 and a capacitor C1 can provide an input EMC filtering stage for an input signal received on first and second terminals BLK, WHT. In one embodiment, the first input terminal BLK corresponds to a conventional black wire and the second input terminal WHT corresponds to a conventional white wire on which a standard 120 V AC signal can be provided.

[0030] In general, the power control circuits 108,112 select conduction and non-conduction regions for the switching elements 102, 104 such that energy storage devices, e.g., bulk storage capacitors, are charged to a predetermined level even in the presence of non-linear loads. That is, so-called peak charging of the capacitor at the peak of the line voltage is eliminated. In addition, surge current levels are significantly reduced as compared with conventional circuits.

[0031] FIG. 4 shows an exemplary circuit implementation of the circuit of FIG. 3, in which like reference numbers indicate like reference elements. It is understood that the first and second power control circuits 108,112 may be active in opposite half cycles of the AC signal to the load 106. It is further understood that the operation of only one of the power control circuits will be explained since operation of the second mirrors that of the other. In addition, while first and second power control circuits are shown, alternative embodiments are contemplated having a single power control circuit for controlling one of the switching elements.

[0032] The first and second switching elements 102, 104 are shown as MOSFET devices each having respective gate Q01G, Q11G, source Q01S, Q11S, and drain Q01D, Q11D terminals. The source terminal Q11S of the first switching element is coupled to the first rail 110 and the drain terminal Q11D is coupled to a first terminal 106a for connection to the load. The gate terminal Q11G is coupled to the first power control circuit 108. The drain Q01D of the second switching element Q01 is coupled to a second load terminal 106b and the source Q01S is coupled to the second voltage rail 114. And the gate terminal Q01G is coupled to the second power control circuit 112.

[0033] While the switching devices are shown as Bipolar Junction Transistors (BJTs) and Field Effect Transistors (FETs), it will be readily understood by one of ordinary skill in the art that a wide variety of switching devices can be used in other embodiments to meet the requirements of a particular application. It is also understood that while a half bridge configuration is shown, a variety of other circuit arrangements, such as full bridge topologies, can be used without departing from the present invention.

[0034] Looking to the bottom right of FIG. 4, the second power control circuit 112 includes a first control switching element Q02, here shown as a bipolar transistor having a base B, a collector C, and an emitter E terminal. The collector terminal C is coupled to the gate Q01G of the first switching element Q01 and the emitter terminal E is coupled to the second voltage rail 114. A first potentiometer P01 has a first terminal coupled to the second voltage rail 114 and a second terminal coupled to the base terminal B, which is coupled to the first voltage rail 110 via a resistor RR1 and a diode DR1.

[0035] A first capacitor C01, a first resistor R01, and a first diode D01 are coupled end-to-end across the first and second rails 110, 114. Second and third resistors R02, R03 are coupled in series from the gate terminal Q01G to a point between the first capacitor C01 and the first resistor R01. A capacitor CD can be coupled from the second rail 114 to a point between the second and third resistors R02, R03.

[0036] In operation, as the circuit operates to energize the load 106, the second switching element 104 is biased to the conductive state by a potential applied to the gate terminal Q01G by energy stored in the first capacitor C01, which charges via the first diode D01 and the first resistor R01. The energy stored in the first capacitor C01 maintains the conductive state of the second switching element 104. The first switching element 102 is biased to the conductive state by the first power control circuit 108 in a similar manner to provide an AC signal to the load 106. Control of each of the switching elements 102, 104 is being performed on a half cycle basis, while the conduction function of the opposite switching element is performed by conventional first and second free-wheeling diodes FW1, FW2 connected across the respective transistors.

[0037] When the voltage across the first potentiometer P01 becomes greater than a predetermined threshold V_{th} this potential, which is applied to the base B of the first control switching element Q02, causes the first control switching element to transition to the conductive state. As the first control switching element Q02 becomes conductive, the gate Q01G of the second switching element 104 is coupled to the second rail 114 so as to turn the second switching element off. Thus, the potentiometer P01, which “reads” the voltage between the first and second voltage rails 110, 114 in combination with resistor RR1 and diode DR1, can be adjusted to select the predetermined threshold voltage V_{th} across the rails 110, 114 that is effective to turn the second control switching element Q02 ON (conductive) and consequently the second switching element 104 is turned OFF (non-conductive).

[0038] In one embodiment, the first and second power control circuits 108, 112 mirror operation of each other with matched potentiometers so that the first and second switching elements 102, 104 are turned off at substantially the same point in the AC load waveform.

[0039] FIG. 4A shows the circuit of FIG. 4 with the addition of component characteristic values. It is understood that exemplary values for circuit components are shown without

limiting the invention to any particular values. One of ordinary skill in the art can readily vary component characteristics to meet the needs of a particular application.

[0040] FIG. 5A, in combination with FIG. 4, shows the points PNC1, PNC2 at which the first and second switching elements 102, 104 turn non-conductive and the points PC1, PC2 at which the first and second switching elements turn conductive. For each half cycle there is a non-conductive region NCR1, NCR2 during which one of the switching elements 102, 104 is non-conductive. As can be seen, when the voltage on the potentiometer P01 reaches the voltage threshold V_{th} , which corresponds to the peak charging voltage V_c , the active switching element 102 or 104 for the half cycle turns off at point PNC1 until a corresponding point PC1 when the signal across the first and second rails 110, 114 falls below the voltage threshold V_{th} and the switching element 102 or 104 becomes conductive again. The voltage threshold V_{th} on the potentiometer P01 corresponds to a voltage level V_c across the first and second AC rails 110, 114, which can be below the peak voltage level V_p of the AC load signal.

[0041] FIG. 5B shows the current surges CS1-4 that correspond to the transition points PNC1, PNC2, PC1, PC2 of FIG. 5A. As can be seen, there are four current surges Cs1-4 per cycle instead of two current surges in conventional circuits. The frequency of the current surges is twice that of the input signal. For example, the current surge frequency may be about 120 Hz instead of 60 Hz so as to reduce visible light flicker and reduce noise. In addition, the magnitude of the four current surges CS1-4 is significantly less than current surges at the AC signal peak in conventional circuit, so as to significantly reduce stress on the circuit components.

[0042] In addition, energy storage elements, such as bulk capacitors, charge to the voltage level of the AC signal at the transition points PC1, PNC1, PC2, PNC2. Thus, the voltage level V_c to which storage capacitors charge can be selected by adjusting the potentiometer P01 in the power control circuit 112. Once again, it is understood that references to components and operation of the second power control circuit 112 are also

applicable to the first power control circuit 108 and the first switching element 102. Furthermore, the non-conductive regions NCR1, NCR2 can be sized to meet the needs of a particular application, such as dimming. For example, the light source brightness can correspond to the voltage level V_c (FIG. 5A) to which storage elements charge, thus directly controlling the DC voltage available to the power circuit.

[0043] FIG. 5C shows an exemplary embodiment in which the threshold voltage V_{th} for the potentiometer P01 is selected to limit the charging voltage V_c to a level that is slightly above the expected peak voltage V_p of the AC signal. If there is a voltage surge, the AC signal voltage is clamped at V_c and a non-conductive region is created during the time during which the voltage across the first and second rails 110, 114 is above the expected peak voltage V_p . Thus, overvoltage protection is provided by clamping the voltage level.

[0044] FIG. 6 shows a circuit 100' having power management including current surge protection in accordance with the present invention. It is understood that certain features described below are added to the circuit of FIG. 4, for which like reference numbers indicate like elements. In an exemplary embodiment, the first power control circuit 112' includes a sense resistor RF01 coupled between the source terminal Q01S of the second switching element and the second AC rail 114. A diode DF01 is coupled between the source terminal Q01S and the base B of the first control switching element Q02. A capacitor CF01 is coupled between the base terminal B and the second AC rail 114 such that the sense resistor RF01, capacitor CF01 and diode DF01 form a current limiting mechanism in conjunction with the second control switching element Q02.

[0045] If the current through the second switching element 104 generates a voltage across the sense resistor RF01 that is greater than a predetermined voltage sufficient to bias the first control switching element Q02 to the conductive state via the base terminal B, the second switching element 104 is turned off. Thus, current through the second switching element 104 is limited to a predetermined level. It is understood that an impedance level of capacitor CF01 can be selected to maintain the first control switching element Q02 to

the conductive state for a predetermined amount of time, which can correspond to a desired number of AC signal cycles.

[0046] FIG. 7 shows a further embodiment of a circuit 200 having power management in accordance with the present invention. The circuit 200 includes a first control circuit 202 and a second control circuit 204 coupled on either side of a load 206, which can be a non-linear load. A series of resistors RC1-4 and a potentiometer P1 are coupled end-to-end across first and second AC rails 208, 210.

[0047] The first control circuit 202 includes first and second switching elements Q11, Q21, here shown as BJTs, coupled in a Darlington configuration, for energizing the load 206. A third switching element Q31, also shown as a BJT, has an emitter terminal E coupled to the first AC rail 208, a base terminal coupled to a point between the first and second resistors RC1, RC2, and a collector terminal coupled to the base terminal of the second switching element Q21 of the Darlington pair. A diode D11 is coupled between the first AC rail 208 and the load 206 for enabling activation of the circuit during negative half cycles of the AC signal from black and white input terminals BLK, WHT. The second control circuit 204 mirrors the first control circuit for the other half cycle.

[0048] In operation, when a voltage between the first and second AC rails 208, 210 is greater than a predetermined threshold voltage, the third switching element Q31 is biased to the conductive state. As the third switching element Q31 is turned ON, the second and first switching elements Q21, Q11 of the Darlington pair are turned off. The resultant AC signal to the load is similar that shown in FIG. 5A, in which the voltage is clamped to a predetermined level V_c . The selected resistance of the potentiometer P1 determines the clamping voltage V_c of the circuit. It is understood that the clamping voltage can be selected to be below the expected peak signal voltage V_p , such as for dimming applications, or above the expected peak signal voltage V_p , for overvoltage protection.

[0049] FIG. 8 shows the circuit of FIG. 7 with the addition of surge current protection in accordance with the present invention. The first control circuit 202 includes a sense resistor RF coupled between the first AC rail 208 and the first resistor RC1. If the load current becomes greater than a predetermined amount set by the potentiometer P1, the voltage across the sense resistor RF biases the third switching element Q31 to the conductive state so as to turn the Darlington pair Q21, Q11 off.

[0050] FIG. 9 shows a further circuit 300 having power management in accordance with the present invention referenced to a single AC rail. It is understood that the circuit topology and operation is similar to that shown and described in conjunction with FIG. 7, for example. The circuit 300 includes a first input terminal BLK and a second input terminal WHT, which is coupled to a load LD.

[0051] The circuit 300 includes a single potentiometer P1, a scaling resistor RSC, and the load terminals (including the second input terminal WHT coupled end-to-end, as shown. The potentiometer P1 provides a voltage that biases respective control switching elements Q31, Q32 to a conductive state if the load voltage increases above a predetermined amount determined by the setting of the potentiometer. The control switching elements Q31, Q32, when conductive, turn off the respective Darlington pairs Q12, Q22, and Q21, Q31 to provide selected periods of non-conduction.

[0052] In one particular embodiment, such as that shown in FIG. 10, the scaling resistor RSC is in the order of about 1 M Ω so as to maintain current to a level within applicable safety standards, such as UL (Underwriters Laboratories). Further exemplary circuit component characteristic values are shown. It is understood that for this, and any other embodiment herein, that component values are merely illustrative and can be readily varied by one of ordinary skill in the art. It is understood that this particular arrangement is useful, for example, in the case where one of the terminals, e.g., the white wire, is not readily accessible.

[0053] FIG. 10 shows a further exemplary embodiment 400 similar to that shown in FIG. 9 where circuit is referenced to ground. It is understood that the potential difference between the white wire terminal WHT and GND is relatively small since the difference corresponds to the amount of current flow through the scaling resistor RSC. For example, $120\text{V}/1\text{M}\Omega = 120\mu\text{A}$, which is well within applicable UL safety standards for ground fault current.

[0054] FIG. 11 shows a further embodiment 400' of the circuit of FIG. 10 with the addition of current limiting functionality including first and second sense resistors RF1, RF2. If the current through the load is greater than a predetermined threshold determined by the potentiometer P1, the voltage generated across the sense resistors RF1, RF2 biases the respective first and second control switching elements Q31, Q32 to the conductive state so as to turn the circuit off.

[0055] FIG. 12 shows another embodiment of a circuit 500 having power management in accordance with the present invention. An input waveform on first and second input terminals BLK, WHT is rectified by a full bridge rectifier D1, D2, D3, D4. The circuit 500 further includes first and second switching elements Q1, Q2, here shown as BJTs in a Darlington configuration, for energizing a load LD. The collector terminals C1, C2 of the switching elements Q1, Q2 are coupled to a first rail RL1 such that the switching elements are normally in saturation. An emitter terminal E of the first switching element Q1 is coupled to the second rail RL2 via a sense resistor RF. A triac TR is coupled across the first and second rails RL1, RL2 with a gate G coupled to a diode DPM1. A sense capacitor CF is coupled between the triac gate G and the second rail RL2. A resistor RC can be coupled in parallel with the sense capacitor.

[0056] When the voltage across the sense resistor RF increases above a predetermined level, the potential at the gate G of the triac bias the triac to the conductive state so as to turn the first and second switching elements Q1, Q2 off until the next zero crossing. The energy stored in the sense capacitor CF can maintain the triac in the conductive state to

provide duty cycle control. That is, the circuit can remain off for a number of AC cycles. This circuit can be considered to be a self-resetting electronic fuse.

[0057] It is understood that the power management circuits shown and described above have a wide variety of applications including, but not limited to, circuit protectors, voltage regulators, and electronic fuses.

[0058] One skilled in the art will appreciate further features and advantages of the invention based on the above-described embodiments. Accordingly, the invention is not to be limited by what has been particularly shown and described, except as indicated by the appended claims. All publications and references cited herein are expressly incorporated herein by reference in their entirety.

What is claimed is: